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Bermudagrass (*Cynodon* spp) dose–response relationships with clethodim, glufosinate and glyphosate

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Abstract: Greenhouse studies were conducted to evaluate the sensitivity of three commercial cultivars, eight experimental cultivars and common bermudagrass to clethodim, glufosinate and glyphosate. Each herbicide was applied at eight doses. Data were regressed on herbicide dose using a log-logistic curve ($R^2 = 0.56$–0.95 for clethodim, $R^2 = 0.60$–0.94 for glufosinate, and $R^2 = 0.70$–0.96 for glyphosate). The herbicide rate that elicited a 50% plant response (I_{50}) in the bermudagrass cultivars ranged from 0.04 to 0.19 kg ha^{-1} clethodim, 0.19 to 1.33 kg ha^{-1} glufosinate and 0.34 to 1.14 kg ha^{-1} glyphosate. Relative to other cultivars, common bermudagrass was intermediate in its response to clethodim and among the most tolerant cultivars to glufosinate and glyphosate. *TifSport* was relatively tolerant to clethodim and glufosinate compared with other cultivars, but relatively sensitive to glyphosate. One cultivar, 94-437, was consistently among the most sensitive cultivars to each of the herbicides. While there were differential herbicide tolerances among the tested bermudagrass cultivars, there did not appear to be any naturally occurring herbicide resistance that could be commercially utilized. However, research indicated that breeding efforts should target herbicide resistance that is at least four times the registered use rate. Also, *TifSport* and *Tifway* have been identified as suitable representatives of triploid hybrid bermudagrass cultivars to be used to evaluate the success of turfgrass renovation programs.

Keywords: bermudagrass; clethodim; *Cynodon*; dose response study; glufosinate; glyphosate; triploid interspecific hybrid bermudagrass

1 INTRODUCTION

1.1 Methyl bromide alternatives

Methyl bromide is the most common soil fumigant used in the turfgrass industry, and is an important component of turfgrass renovation programs when a new turfgrass replaces a previous cultivar.[1–4] Contamination of new turfgrass by the previous turfgrass cultivars can create significant problems for sod-producers, golf course managers and various athletic fields due to potential differences among the cultivars (eg winter hardiness, optimum mowing height and pest tolerance).[2,4] However, methyl bromide has been identified as a potential Class I ozone-depleting substance, and its production and use in agricultural systems will be eliminated, or at the very least severely limited, after 2005.[5,6]

One potential alternative to methyl bromide in turfgrass renovation systems involves the development of non-pollen- and non-seed-forming herbicide-resistant turfgrasses,[7,8] such as hybrid bermudagrass cultivars.[9,10] New herbicide-resistant cultivars can be developed by traditional breeding or utilizing transgenic technology (ie genetically modified organisms). Development of herbicide-resistant bermudagrass cultivars could allow managers to more efficiently manage weeds (including bermudagrass species) with environmentally benign herbicides.

1.2 Triploid hybrid bermudagrass cultivars differ from common bermudagrass

Common bermudagrass, *Cynodon dactylon* (L) Pers, was first introduced to the USA in Savannah, GA in 1751,[11] and has become a significant weed throughout the southern USA.[12] Common bermudagrass has a tenacious growth habit, thriving in hot weather and colonizing sites inhospitable to other plants. These attributes have allowed the use of common bermudagrass as a forage crop, a barrier to soil erosion and a turfgrass species.[11] Breeding programs have improved qualities

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of bermudagrass cultivars to meet the needs of the turfgrass industry. For instance, triploid interspecific hybrid bermudagrass cultivars, such as *TifEagle* and *TifSport*, have various desirable characteristics such as high turf quality, tolerance to close mowing, improved winter hardiness, and resistance to pests [eg southern mole cricket (*Scapteriscus borellii* Giglio-Tos)].[13,14] Common bermudagrass has an aggressive spreading growth habit and is capable of reproducing through seed production or vegetative propagation. In contrast, triploid hybrid bermudagrass cultivars tend to be less aggressive in their growth habit,[15] are sterile (ie unable to produce pollen or seed), and are propagated vegetatively. When grown from similar initial plant diameters in the absence of plant competition, common bermudagrass plants increased in size >3.8 times and >1.5 times relative to plants of *TifEagle* and *TifSport*, respectively.[8] Triploid hybrid bermudagrass cultivars were more sensitive than tetraploid bermudagrasses (ie common bermudagrass) to clethodim, clethodim plus glyphosate, dalapon, glyphosate, quizalofop and trichloroacetic acid.[8,16] As a result, common bermudagrass and triploid hybrid bermudagrass cultivars should be considered distinctly different.

Previous research evaluated the sensitivities of various bermudagrass populations to glyphosate,[8,17–22] clethodim[8,23–27] and glufosinate.[28] However, these studies did not evaluate the relationship between herbicide dose (all studies tested up to three herbicide rates) and bermudagrass growth over a broad range of herbicide rates. Many of these studies evaluated control of common bermudagrass in agronomic crops[23–28] and not in highly managed turfgrass environment. The objective of this study was to characterize the dose–response of common bermudagrass, three commercial triploid hybrid cultivars and eight experimental triploid hybrid cultivars to three common herbicides. Evaluation of the relative herbicide sensitivities of these bermudagrass cultivars provides knowledge of these bermudagrass cultivars that can be used in the development of herbicide-resistant turf-bermudagrass cultivars.

2 MATERIALS AND METHODS

2.1 Herbicide dose

A dose–response study was conducted in greenhouses in 2001 at the Coastal Plain Experiment Station in Tifton, GA (CPES). Each herbicide was applied at eight doses on a geometric scale (with a multiplier of two) and included: 0, 0.0625, 0.125, 0.25, 0.5, 1, 2, and 4 times the registered herbicide use rate. The registered use rates were considered 0.14 kg AI ha^{-1} for clethodim, 0.84 kg AI ha^{-1} for glufosinate and 0.84 kg AE ha^{-1} for glyphosate. Herbicide applications were made using a carbon dioxide-pressurized backpack sprayer calibrated to deliver 187 liter ha^{-1} at 138 kPa. Each treatment was replicated four times in a randomized complete block design and the study was repeated over time.

2.2 Test species

Each treatment was applied to 12 bermudagrass cultivars, including: tetraploid ($4n = 36$) common bermudagrass (15 cm tall at application) from a naturalized population at CPES, three commercially available triploid ($3n = 27$) interspecific (*Cynodon dactylon* (L) Pers × *Cynodon transvaalensis* Burtt-Davy) hybrid bermudagrass cultivars [*TifEagle* (9 cm tall at application),[10,14] *TifSport* (12.5 cm tall at application),[9,13] and *Tifway* (10 cm tall at application)[29]], and eight experimental triploid interspecific hybrid bermudagrass cultivars under development [94-281 (13 cm tall at application), 94-310 (14 cm tall at application), 94-317 (10 cm tall at application), 94-373 (10 cm tall at application), 94-398 (6 cm tall at application), 94-430 (13 cm tall at application), 94-437 (8 cm tall at application) and 97-4 (4 cm tall at application)]. Bermudagrass plugs were collected from a field nursery in November 2000 and grown in the greenhouse in pots (15 cm diameter) until treatment in January and February 2001.

2.3 Data collection

Turfgrass color ratings, an indication of plant health and aesthetic quality, were rated on a scale of 1 (brown, desiccated plant) to 9 (green, healthy plant) at 17 days after treatment (DAT). Above-ground foliage was clipped to soil level at 17 DAT and plants were allowed to re-grow for 14 days. Plant vigor was rated on a scale of 1 (dead plant) to 9 (thriving plant) at 31 DAT.

2.4 Data analysis

Data were examined using analysis of variance. Lack of a significant treatment by repetition of the study interaction indicated that data could be pooled. Data were then analyzed using log-logistic regression.[30] The relationship between dependent variables (ie plant color and vigor ratings) and herbicide rate for each cultivar and herbicide were fitted to the log-logistic model:

$$y = C + \left[\frac{D - C}{1 + \left(\frac{x}{\mathrm{I}_{50}} \right)^{\beta}} \right] \qquad (1)$$

where C = the mean response at the highest herbicide rate, D = the mean response of the untreated control, I_{50} = herbicide rate (kg ha^{-1}) providing 50% response and β = slope of the line at I_{50}.[30] Differences among parameters estimates (ß and I_{50}) were evaluated using a *t*-test:

$$t = \frac{\mathrm{Estimate_A} - \mathrm{Estimate_B}}{\sqrt{(\mathrm{SE_{Estimate_A}})^2 + (\mathrm{SE_{Estimate_B}})^2}} \qquad (2)$$

where the numerator is the difference in parameter estimate values and the denominator is the standard error of the differences of the parameter estimate values.[31]

3 RESULTS AND DISCUSSION

3.1 Clethodim dose response

3.1.1 Plant color rating 17 DAT

Bermudagrass plant color ratings decreased as clethodim rate increased, and the relationship fitted a log-logistic regression ($R^2 = 0.56$–0.81) (Table 1). There were no detectable differences in ß for ratings of plant color among the bermudagrass cultivars, indicating that each cultivar had a similar response to clethodim rate around I_{50}. Common bermudagrass I_{50} for clethodim (0.09 kg ha^{-1}) was lower than I_{50} values (required a lower rate of clethodim to reduce growth 50%) for 94-373, *TifSport, Tifway*, 94-430, 94-437 and 97-4 (Table 1). All cultivars had higher I_{50} values than 94-317 (0.05 kg ha^{-1}). With the exception of *TifSport* and *Tifway*, 94-373 had a higher I_{50} than all other cultivars. All cultivars had the minimum plant color rating when clethodim was applied at four times the registered use rate (0.56 kg ha^{-1}).

3.1.2 Plant vigor rating 31 DAT

The relationships between clethodim rate and bermudagrass plant vigor following clipping was described by log-logistic regression for each of the cultivars ($R^2 = 0.81$–0.95) (Fig 1). Differences in ß and I_{50} between common bermudagrass and all other cultivars could not be detected. The cultivar with the shallowest slope (least responsive to changes in clethodim rate around I_{50}) was 97-4, possessing a lower ß value than 94-310, 94-317 and *TifSport* (Table 2). *TifSport* had a higher I_{50} (0.09 kg ha^{-1}) than 94-310, 94-398 and 94-437. All other cultivars had similar I_{50} values for clethodim in terms of plant vigor (36–71% of the registered use rate).

Field research indicated that 0.29 kg ha^{-1} clethodim controlled common bermudagrass 60–95% in sunflower (*Helianthus annuus* L)[26] and 30–86% in cotton (*Gossypium hirsutum* L).[8] Clethodim applied at 0.14 kg ha^{-1} controlled common bermudagrass 61–86% in peanut (*Arachis hypogaea* L),[24] while 0.28 kg ha^{-1} clethodim controlled common bermudagrass 66% at peanut harvest and 72% the following summer.[27] Two applications of 0.3 kg ha^{-1} clethodim separated by four weeks controlled common bermudagrass 59–98% and triploid hybrid cultivars (*TifEagle* and *TifSport*) 98%.[8]

3.2 Glufosinate dose response

3.2.1 Plant color rating 17 DAT

Log-logistic regression described the relationship between bermudagrass plant color and glufosinate rate ($R^2 = 0.65$–0.94) (Table 2). Differences in ß among the bermudagrass cultivars for ratings of plant color could not be detected with glufosinate. Common bermudagrass had a higher I_{50} (0.48 kg ha^{-1}) than 94-373, 97-4, *TifEagle* and 94-430, but was similar to all other cultivars. *TifSport* and *Tifway* had higher I_{50} values (0.50 kg ha^{-1}) than 94-310, 94-373, 94-430, 94-437, 97-4 and *TifEagle*. Glufosinate applied at twice the registered rate (1.68 kg ha^{-1}) resulted in the lowest plant color rating for all cultivars.

3.2.2 Plant vigor rating 31 DAT

Bermudagrass plant vigor was reduced as glufosinate rate increased for all cultivars and fitted a log-logistic regression ($R^2 = 0.60$–0.83) (Fig 2). Common bermudagrass had a higher ß value than 94-437, *TifEagle, TifSport* and *Tifway*, indicating a greater sensitivity to glufosinate around the I_{50}. Differences in ß among all of the other cultivars could not be detected. Common bermudagrass I_{50} indicated intermediate sensitivity to glufosinate (0.91 kg ha^{-1}), similar to all cultivars except 94-373 and *TifEagle*. *TifSport* was the most tolerant of glufosinate (1.33 kg ha^{-1}), possessing

Table 1. Parameter estimates of the log-logistic regression describing the relationship between plant color rating and plant vigor rating and rate of clethodim for 12 bermudagrass cultivars

	Plant color rating 17 DAT			Plant vigor rating 31 DAT		
Cultivar	ß (±SE)	I_{50} (±SE)[a]	R^2	ß (±SE)	I_{50} (±SE)[a]	R^2
94-281	1.25 (±0.32)	0.12 (±0.011)	0.61	2.66 (±0.33)	0.07 (±0.022)	0.92
94-310	1.56 (±0.35)	0.08 (±0.004)	0.72	3.11 (±0.35)	0.04 (±0.001)	0.95
94-317	1.22 (±0.19)	0.05 (±0.001)	0.78	4.59 (±0.97)	0.10 (±0.036)	0.90
94-373	1.25 (±0.37)	0.19 (±0.020)	0.56	2.56 (±0.35)	0.07 (±0.017)	0.91
94-398	1.47 (±0.35)	0.09 (±0.001)	0.67	2.16 (±0.31)	0.04 (±0.017)	0.86
94-430	1.21 (±0.24)	0.14 (±0.014)	0.71	2.23 (±0.29)	0.08 (±0.020)	0.90
94-437	1.34 (±0.32)	0.13 (±0.004)	0.65	2.80 (±0.65)	0.04 (±0.015)	0.81
97-4	1.10 (±0.18)	0.12 (±0.001)	0.76	1.99 (±0.21)	0.07 (±0.018)	0.92
Common	1.11 (±0.27)	0.09 (±0.018)	0.62	3.35 (±0.68)	0.06 (±0.031)	0.86
TifEagle	1.51 (±0.24)	0.08 (±0.004)	0.81	2.54 (±0.31)	0.07 (±0.017)	0.93
TifSport	1.29 (±0.29)	0.18 (±0.022)	0.67	3.36 (±0.57)	0.09 (±0.015)	0.91
Tifway	1.34 (±0.23)	0.17 (±0.020)	0.76	2.53 (±0.42)	0.05 (±0.017)	0.86

[a] I_{50} is the rate of clethodim (kg ha^{-1}) required to elicit a 50% change in plant response.

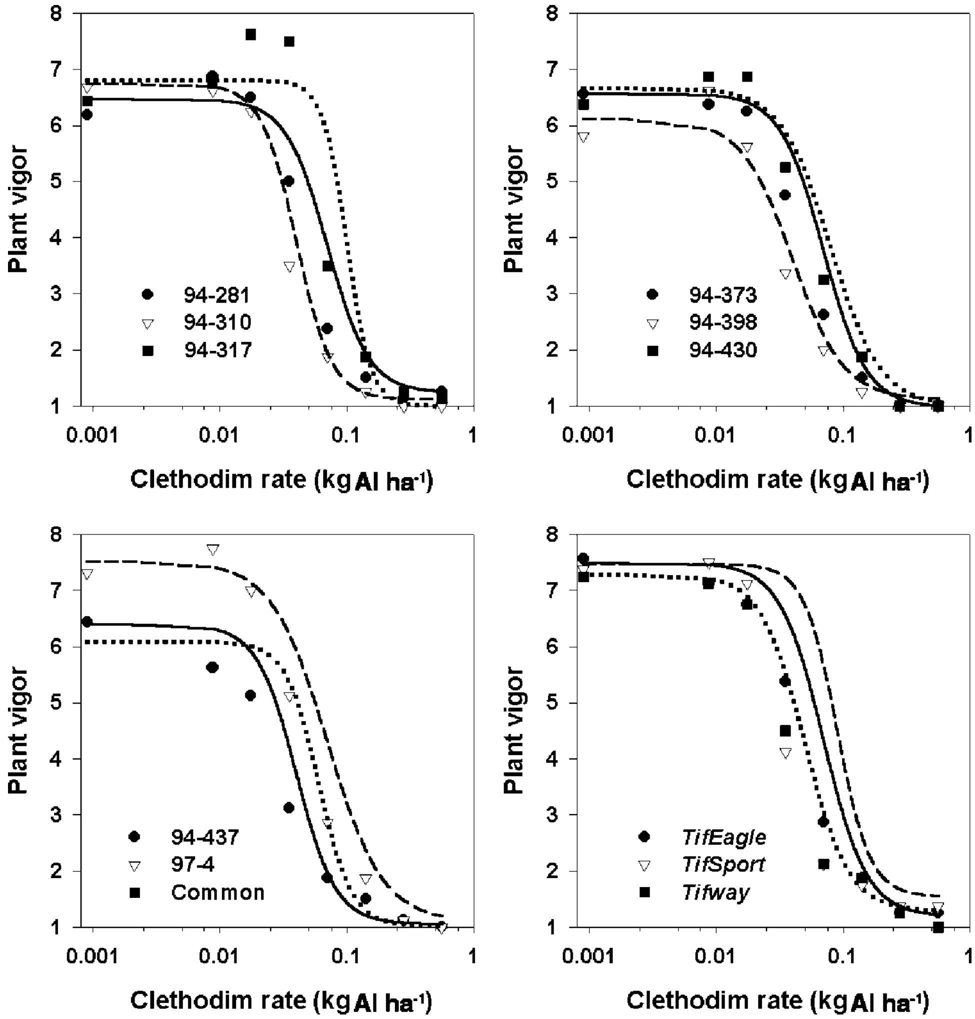

Figure 1. The relationship between rate of clethodim and plant vigor rating at 31 days after treatment for 12 bermudagrass cultivars. Parameter estimates for the log-logistic regression are found in Table 1.

Table 2. Parameter estimates of the log-logistic regression describing the relationship between plant color rating and plant vigor rating and rate of glufosinate for 12 bermudagrass cultivars

	Plant color rating 17 DAT			Plant vigor rating 31 DAT		
Cultivar	ß (±SE)	I_{50} (±SE)[a]	R^2	ß (±SE)	I_{50} (±SE)[a]	R^2
94-281	2.71 (±1.02)	0.44 (±0.15)	0.65	2.81 (±0.99)	0.73 (±0.24)	0.60
94-310	1.76 (±0.36)	0.36 (±0.04)	0.75	1.91 (±0.40)	1.02 (±0.20)	0.75
94-317	1.66 (±0.28)	0.44 (±0.05)	0.79	1.69 (±0.30)	0.87 (±0.13)	0.76
94-373	1.87 (±0.17)	0.19 (±0.03)	0.94	2.07 (±0.38)	0.38 (±0.11)	0.81
94-398	2.07 (±0.28)	0.38 (±0.07)	0.88	1.59 (±0.33)	0.84 (±0.16)	0.66
94-430	1.86 (±0.19)	0.30 (±0.03)	0.92	2.02 (±0.33)	0.88 (±0.17)	0.83
94-437	1.71 (±0.30)	0.33 (±0.02)	0.80	1.44 (±0.24)	0.44 (±0.18)	0.73
97-4	1.74 (±0.39)	0.25 (±0.01)	0.73	1.78 (±0.36)	0.58 (±0.26)	0.72
Common	2.21 (±0.33)	0.48 (±0.08)	0.88	2.81 (±0.60)	0.91 (±0.19)	0.79
TifEagle	1.87 (±0.40)	0.28 (±0.06)	0.76	1.44 (±0.28)	0.50 (±0.03)	0.68
TifSport	1.64 (±0.38)	0.50 (±0.03)	0.67	1.42 (±0.32)	1.33 (±0.22)	0.60
Tifway	1.58 (±0.31)	0.50 (±0.09)	0.71	1.38 (±0.30)	0.80 (±0.12)	0.62

[a] I_{50} is the rate of glufosinate (kg ha^{-1}) required to elicit a 50% change in plant response.

a greater tolerance than 94-373, 94-437, 97-4, *TifEagle* and *Tifway*. In contrast, 94-373 (0.38 kg ha^{-1}) and *TifEagle* (0.50 kg ha^{-1}) were less tolerant to glufosinate than 94-310, 94-317, 94-398, 94-430, common bermudagrass, *TifSport* and *Tifway*.

Broome *et al*[28] found 0.17 kg ha^{-1} glufosinate controlled common bermudagrass 37% at 56 DAT, while 0.45 kg ha^{-1} glufosinate controlled common bermudagrass 80–90% at 56 DAT. Previous research determined glufosinate I_{50} values for annual weeds

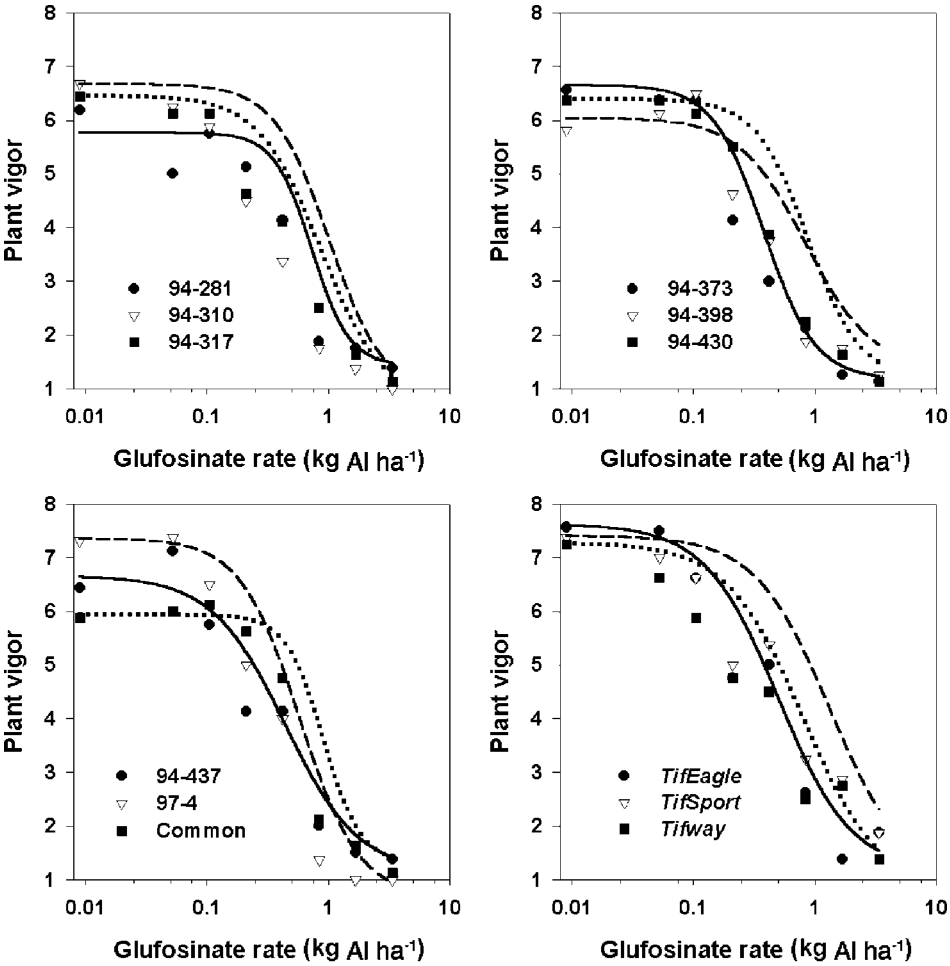

Figure 2. The relationship between rate of glufosinate and plant vigor rating at 31 days after treatment for 12 bermudagrass cultivars. Parameter estimates for the log-logistic regression are found in Table 2.

ranging from 0.06 to 0.24 kg ha^{-1},[32,33] while the I_{50} of perennial yellow nutsedge (*Cyperus esculentus* L) was 0.53 kg ha^{-1}.[34]

3.3 Glyphosate dose response

3.3.1 Plant color rating 17 DAT

Ratings of bermudagrass plant color declined as glyphosate rate increased, with the relationship described by log-logistic regression ($R^2 = 0.75-0.96$) (Table 3). Common bermudagrass ß was not different from that of any other bermudagrass cultivar. The ß value for 94-317 was lower than five of the experimental cultivars (94-281, 94-310, 94-373, 94-398 and 94-437) and *TifSport*. All other ß values were similar among cultivars. Common bermudagrass (1.14 kg ha^{-1}) had a higher I_{50} than all other bermudagrass cultivars. In contrast, 97-4 (0.34 kg ha^{-1}) had a lower I_{50} than all cultivars except 94-317, 94-437 and *TifSport*. Glyphosate applied at four times the registered rate (3.36 kg ha^{-1}) yielded the minimum plant color rating for all cultivars.

3.3.2 Plant vigor rating 31 DAT

The log-logistic regression described the relationship between bermudagrass plant vigor and glyphosate rate ($R^2 = 0.70-0.93$) (Fig 3). With the exception of 97-4, there were no differences in plant vigor ß among cultivars for glyphosate. A high ß value for 97-4 (7.02) indicated a large change in plant sensitivity with the addition of small amounts of glyphosate around the I_{50} value. In addition, I_{50} indicated 97-4 was more sensitive to glyphosate (0.39 kg ha^{-1}) than common bermudagrass and *Tifway*. Differences in I_{50} could not be detected among all of the other cultivars.

Previous research found glyphosate I_{50} values of 0.06–0.16 kg ha^{-1} for annual weeds and 0.45 kg ha^{-1} for yellow nutsedge.[32–34] Glyphosate applied at 0.42 kg ha^{-1} controlled common bermudagrass cultivars $\leq$50%, while 0.84 kg ha^{-1} glyphosate controlled common bermudagrass 75–79% at 35 DAT.[18,19] Glyphosate at 0.84 kg ha^{-1} controlled 17 common bermudagrass ecotypes 38–87% at 42 DAT.[20] Glyphosate applied at 0.84 kg ha^{-1} controlled the triploid hybrid cultivars (*TifEagle* and *TifSport*) $\geq$88% and common bermudagrass 59–100% at 19 weeks after treatment.[8]

4 CONCLUSIONS

The consistent response of bermudagrass to herbicide treatments in repetitions of the study is very unusual.

Table 3. Parameter estimates of the log-logistic regression describing the relationship between plant color rating and plant vigor rating and rate of glyphosate for 12 bermudagrass cultivars

	Plant color rating 17 DAT			Plant vigor rating 31 DAT		
Cultivar	ß (±SE)	I_{50} (±SE)[a]	R^2	ß (±SE)	I_{50} (±SE)[a]	R^2
94-281	2.28 (±0.28)	0.56 (±0.06)	0.91	3.25 (±0.80)	0.83 (±0.26)	0.75
94-310	2.29 (±0.29)	0.63 (±0.08)	0.91	4.43 (±0.91)	0.71 (±0.19)	0.84
94-317	1.44 (±0.23)	0.51 (±0.14)	0.75	3.19 (±0.71)	0.76 (±0.14)	0.81
94-373	2.22 (±0.19)	0.54 (±0.05)	0.95	3.75 (±0.99)	0.52 (±0.28)	0.82
94-398	2.35 (±0.22)	0.54 (±0.03)	0.96	3.88 (±0.94)	0.80 (±0.26)	0.79
94-430	2.02 (±0.22)	0.77 (±0.08)	0.91	4.62 (±1.56)	1.00 (±0.30)	0.77
94-437	3.14 (±0.80)	0.52 (±0.11)	0.82	3.82 (±1.40)	0.56 (±0.38)	0.74
97-4	2.31 (±0.40)	0.34 (±0.08)	0.84	7.02 (±1.32)	0.39 (±0.19)	0.93
Common	1.89 (±0.21)	1.14 (±0.08)	0.90	3.69 (±0.83)	0.99 (±0.21)	0.83
TifEagle	2.34 (±0.41)	0.63 (±0.07)	0.85	2.47 (±0.43)	0.57 (±0.12)	0.85
TifSport	2.43 (±0.38)	0.61 (±0.13)	0.88	3.10 (±0.73)	0.66 (±0.26)	0.81
Tifway	1.81 (±0.25)	0.81 (±0.11)	0.85	2.40 (±0.57)	0.92 (±0.20)	0.70

[a] I_{50} is the rate of glyphosate (kg ha^{-1}) required to elicit a 50% change in plant response.

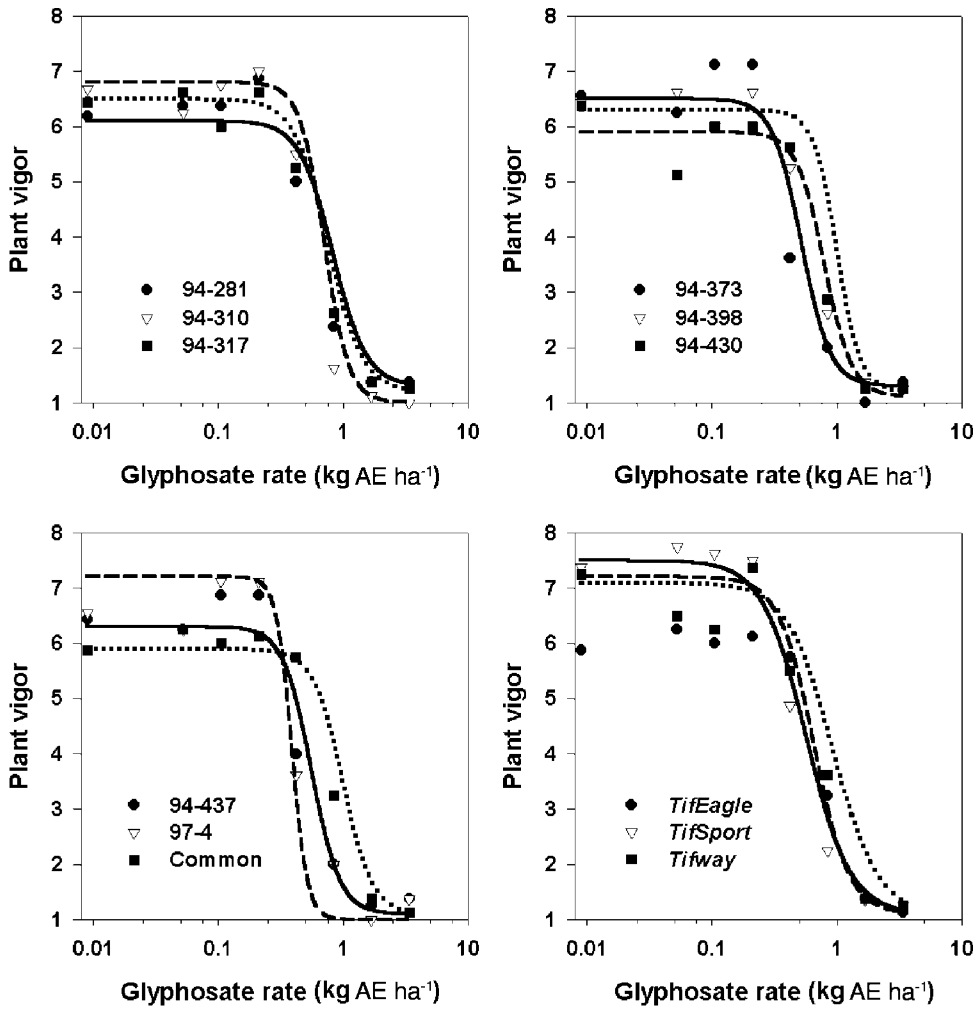

Figure 3. The relationship between rate of glyphosate and plant vigor rating at 31 days after treatment for 12 bermudagrass cultivars. Parameter estimates for the log-logistic regression are found in Table 3.

Other studies have reported substantial variation in bermudagrass response to herbicide application. Differences among bermudagrass plant size have previously been cited as an explanation in variability of control among years and cultivars/ecotypes.[8,19,23,26] The similarity in bermudagrass plant diameters in this study and the consistency in control for each cultivar across repetitions of the study tend to support the contention that differences in size of bermudagrass plants may affect repeatability of results.

Relative to other cultivars, common bermudagrass tended to be intermediate in its response to clethodim and among the most tolerant cultivars to glufosinate and glyphosate. *Tifway* and 94-281 were similar to common bermudagrass in response to each herbicide. *TifSport* exhibited tolerance to clethodim and glufosinate compared with other cultivars, but was relatively sensitive to glyphosate. One cultivar, 94-437, was consistently among the most sensitive cultivars to each of the herbicides. While there were differences in relative herbicide sensitivity among the cultivars, there were not order-of-magnitude differences in I_{50} values, such as are associated with herbicide-resistant ecotypes of other weed species.[35–41] This suggests that the bermudagrass cultivars tested are not resistant to these herbicides and that a broader gene pool needs to be evaluated for natural resistance, or that transgenic technology needs to be utilized to produce herbicide-resistant cultivars.

Research on currently registered soil fumigants has not identified an acceptable alternative to methyl bromide for turfgrass renovation.[2] As such, there is great concern within the turfgrass industry concerning the ability to establish and maintain monocultures of the desired hybrid bermudagrass cultivars.[4] Future research should continue to develop herbicide-tolerant, non-flowering bermudagrass cultivars. Results from this study indicate that herbicide-tolerant bermudagrass cultivars should be developed with a tolerance of at least four times the herbicide use rate ($>0.56\,kg\,ha^{-1}$ clethodim, $>3.36\,kg\,ha^{-1}$ glufosinate and $>3.36\,kg\,ha^{-1}$ glyphosate). In addition, previous studies have indicated that multiple herbicide applications are required during the turf renovation process, therefore herbicide-tolerant cultivars must be able to tolerate multiple herbicide applications.[3,4,22] Because of the relative tolerance of *TifSport* to clethodim and glufosinate, and of *Tifway* to glyphosate, these cultivars would be ideal to evaluate the effectiveness of these herbicides in turf renovations.

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